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Title: PBX 9502 Gas Generation Progress Report FY17

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PBX 9502 Gas Generation Progress Report FY17

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Abstract

The self-ignition ("cookoff") behavior of PBX 9502 depends on the dynamic evolution of gas permeability and physical damage in the material. The time-resolved measurement of product gas generation yields insight regarding the crucial properties that dominate cookoff behavior. We report on small-scale laboratory testing performed in FY17, in which small unconfined samples of PBX 9502 were heated in a small custom-built sealed pressure vessel to self-ignition. We recorded time-lapse video of the evolving physical changes in the sample, quasi-static long-duration pressure rise, then high-speed video and dynamic pressure rise of the cookoff event. We report the full pressure attained during the cookoff of a 1.02g sample in a free volume of 62.5 cm^3.

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1. Introduction

PBX 9502 is an insensitive high-explosive consisting of 95% TATB and 5% Kel-F 800 binder. The explosive is extremely temperature stable. Permeability testing has shown that the material is quite impermeable both at room temperature and after being thermally-cycled[1,2].

Gas Generation experiments conducted in 2016 yielded qualitative high-speed video demonstrating macro-scale crack formation in the ~1s leading up to self-ignition[3]. The 2016 effort was focused on the long-duration slow pressure rise portion of the gas generation.

The goal of the 2017 effort was to capture the full pressure pulse that occurred during the dynamic cookoff event. These data will be valuable to modelers attempting to calculate the mechanical failure of parts and components containing a charge of PBX 9502.

2. Experiment

Descriptions and details of the experiment as originally designed can be found in the 2016 report[3]. Some design modifications were made and are detailed here.

Most importantly, a mounting hole was added to permit a high-temperature pressure transducer to be installed directly into the oven in order to obtain an accurate dynamic pressure rise. The pressure transducer used is a high-temperature Kulite model XTEH-7L-190-3000A (see data sheet Appendix A), with a 3,000psia range.

Numerous other design modifications were made either for cost or efficiency. The outer profile of the oven was changed to a cylindrical shape in order to better accommodate the heating rope. The front windows were modified to allow the oven to be disassembled without removing the heater or insulation, greatly improving efficiency. The material was changed from copper to aluminum to save material costs.

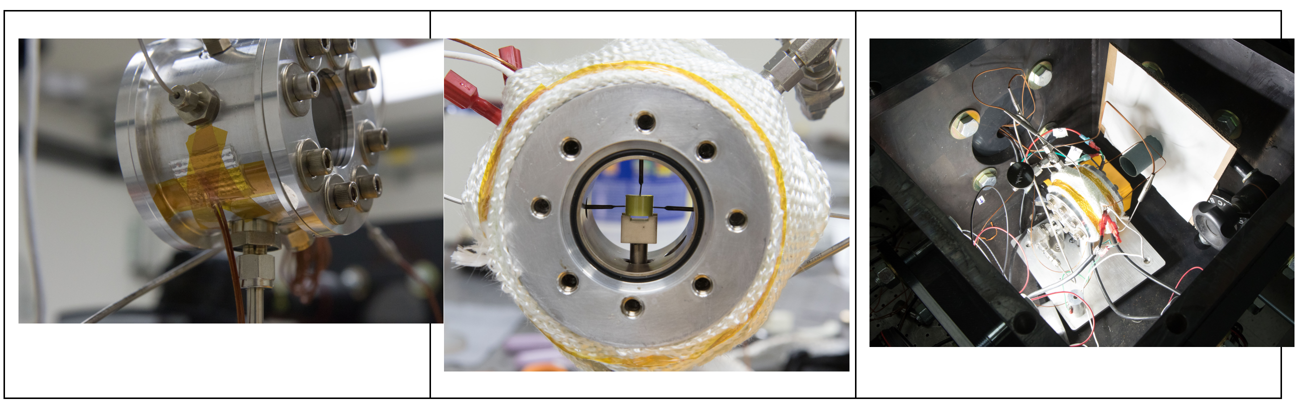


Figure 1. Three photos of oven, sample, and setup prior to testing.

3. Results

Test 07 yielded the most valuable data. The initial heater setpoint was placed at 320˚C which led to a stable oven temperature of 323˚C. After 6228s (103.8 minutes) without signs of self-heating, the heater setpoint was increased to 330˚C which led to a stable oven temperature of 332˚C and was sufficiently hot to cause self-heating and cookoff after an additional 720s (12 minutes). Overall time from start of heating to cookoff was 6948s (115.8 minutes).

Temperature data was captured at 2 Hz; quasi-static pressure data was captured at 2.001121 Hz. Dynamic pressure data was captured at 5MS/s for a duration of 10s (approximately centered on the cookoff event). High-speed video was captured at a rate of 5,000fps. The free volume into which the gas expands was measured to be 62.5 ±0.75 cm^3.

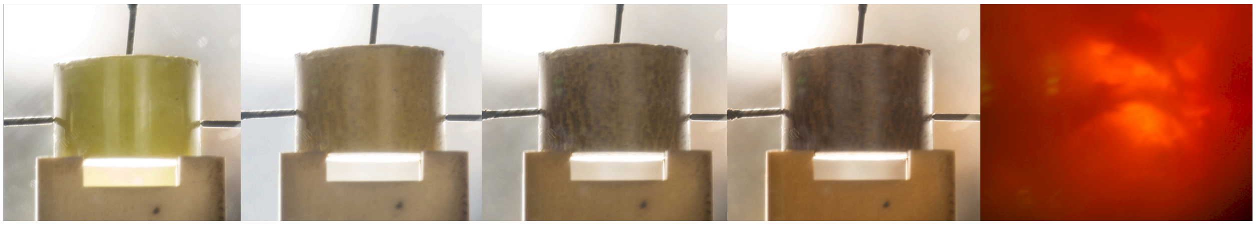


Figure 2. Selected stills from the timelapse sequence, exhibiting thermal damage.

Figure 4 shows the thermocouple traces and quasi-static pressure curve. Figure 5 provides an enlarged detail of the same data in the ~13 minutes prior to thermal runaway.

The full pressure pulse was captured and all gas was contained within the vessel (the vessel remained pressurized without leakage following reaction). This dynamic pressure pulse is shown in Figure 6.

The deflagration consumed most of the material; post-mortem mass of collected material was only .059g (the original mass of the sample was 1.021g). However, the little mass that did remain was found in the form of a large charred mass (attempting to remove the charred mass causes it to disintegrate into dust) (see Figure 3. Image of the sample after cookoff. This material masses only 0.059g (of the original 1.021g pristine sample)).

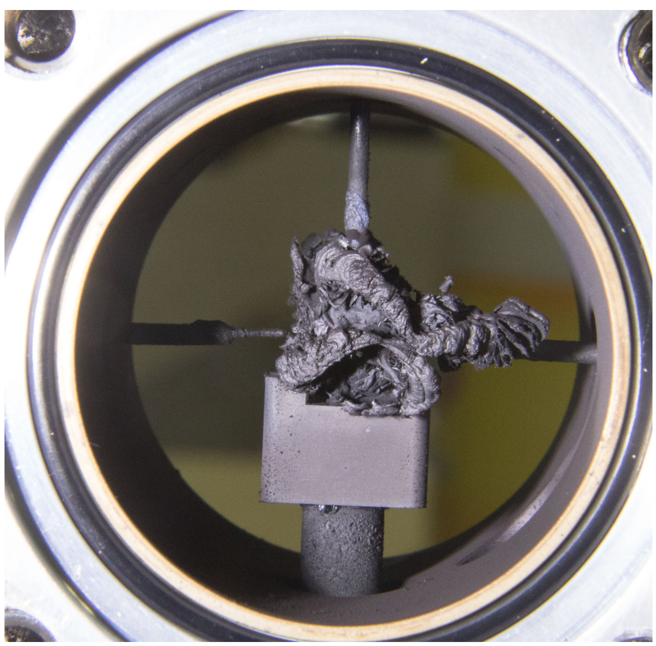


Figure 3. Image of the sample after cookoff. This material masses only 0.059g (of the original 1.021g pristine sample)

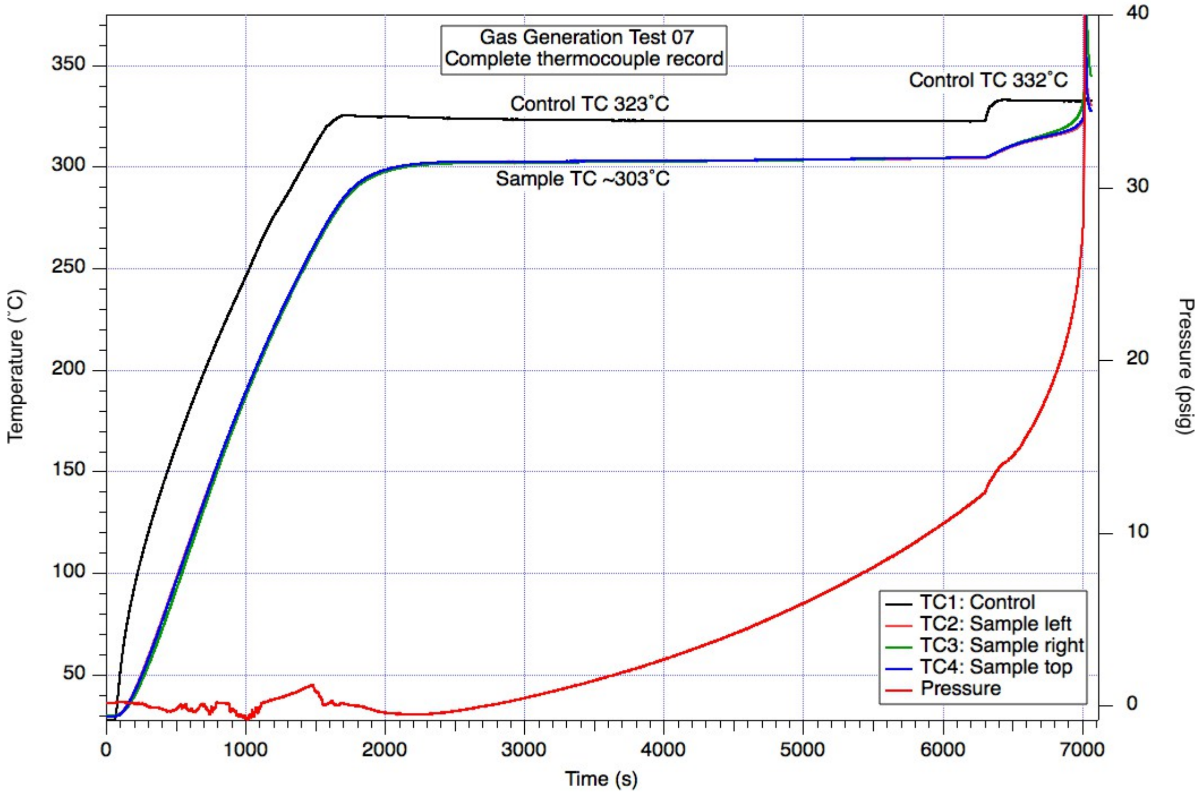


Figure 4. Temperature and pressure over the full test duration.

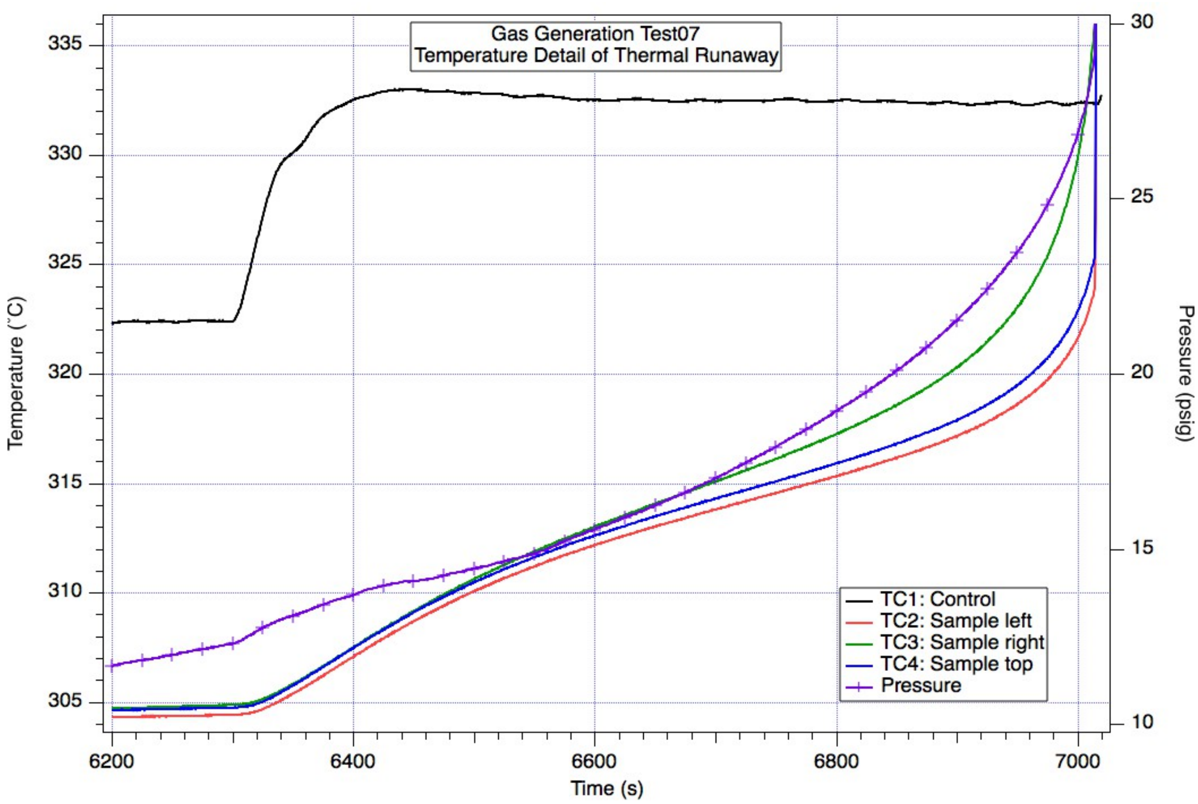


Figure 5. Detail of temperature and pressure last few minutes leading to cookoff.

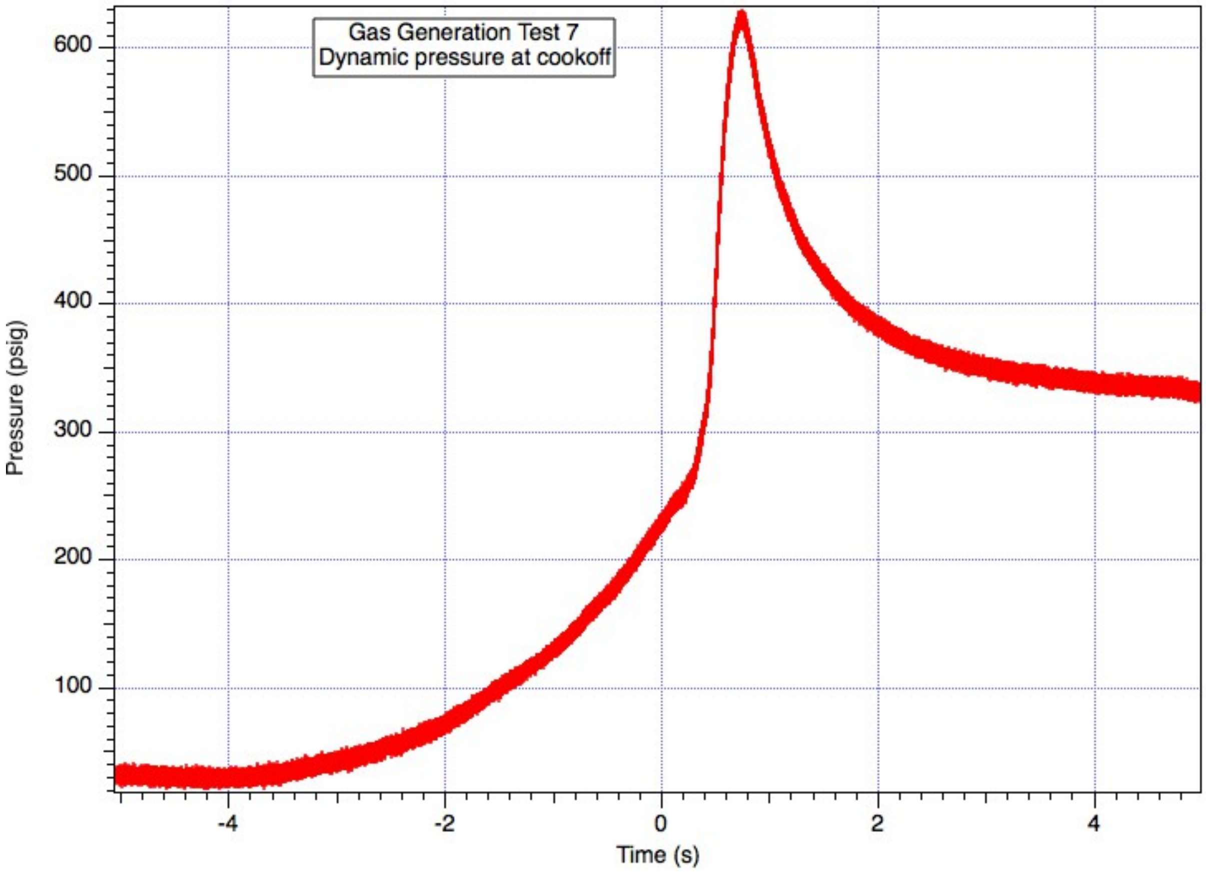


Figure 6. Dynamic pressure rise; the full pulse was recorded and all gas was captured.

4. Conclusions

This work, as well as previous permeability testing, suggest that the PBX 9502 remains impermeable at the micro-scale through cookoff. At cookoff, pockets of gas generated by internal reaction eventually exceed the material strength, then cause cracking. The cracking reveals additional surface area, which contributes to the accelerated gas production and thermal runaway.

For our other explosive—PBX 9501—thermal damage is associated with increased interconnected porosity; this porosity provides dramatically increased surface area for deflagration once self-ignition occurs, and contributes to the ability for PBX 9501 to exhibit considerable post-ignition violence, and in some cases, DDT.

Mounting evidence suggests that, for PBX 9502, the impermeability combined with the thermal stability prevents the formation of porosity that would permit a convective burn. It is possible that, in PBX 9502, large-scale macro-cracks that result from internal pressure exceeding material strength are the dominant mechanism for providing increased surface area for reaction loci during thermal runaway.

5. Future Work

Initial testing in this series was performed with a 10mm diameter x 15mm long cylindrical sample that massed ~2g. Unfortunately, the cookoff of this sample resulted in confinement failure; the bolts threads securing the windows were stripped by the pressure rise. Consequently, the oven was rebuilt with additional bolts, helicoils in the aluminum threads, and the sample size was reduced in an attempt (which was successful) to remain within the strength of the vessel in order to capture the full pressure pulse during cookoff.

The next test to perform should be a repeat of Test 07 in order to check the repeatability of the behavior. Following that, with the strengthened vessel we intend to conduct two tests with 2g of explosive: the first with a single 2g pellet, the second with two 1g pellets. These results will provide us with information regarding the scaling behavior of the gas generation with regard to volume and surface area. Additional testing ideas include the incorporation of confinement sleeves to obtain the gas generation dependence on various confinement geometries and strengths.

6. Data Requests

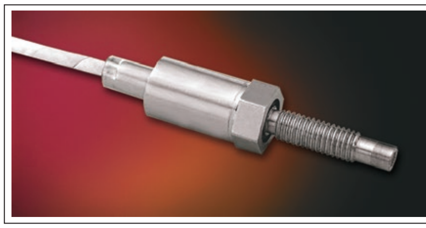
Videos of the tests as well as various other raw data can be made available on request. Please contact Matt Holmes at mholmes@lanl.gov or 505-665-4107.

Appendix A: Pressure transducer datasheet

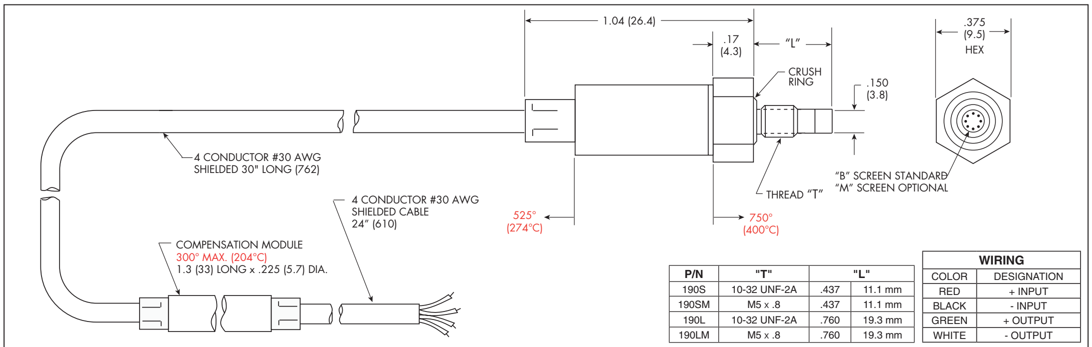
HIGH TEMPERATURE PRESSURE TRANSDUCER

XTEH-7L-190 (M) SERIES

- –65°F To 750°F Temperature Capability
- Patented Leadless Technology **VIS**®
- High Natural Frequency
- Suitable For Turbine Engine Testing



The XTEH Series pressure transducers feature a very wide operating temperature range. These characteristics make these devices ideal for Turbine engine testing. Other equally demanding applications in the industry may also benefit from the ruggedness of these devices.



P/N	"T"	"L"	
190S	10-32 UNF-2A	.437	11.1 mm
190SM	M5 x .8	.437	11.1 mm
190L	10-32 UNF-2A	.760	19.3 mm
190LM	M5 x .8	.760	19.3 mm

WIRING	
COLOR	DESIGNATION
RED	+ INPUT
BLACK	- INPUT
GREEN	+ OUTPUT
WHITE	- OUTPUT

INPUT	Pressure Range	1.7 25	3.5 50	7 100	14 200	21 300	35 500	70 1000	140 2000	210 BAR 3000 PSI
	Operational Mode	Absolute, Sealed Gage								
	Over Pressure	2 Times Rated Pressure to a Maximum of 4500 PSI (310 BAR)								
	Burst Pressure	3 Times Rated Pressure to a Maximum of 5000 PSI (350 BAR)					1.5 Times Rated Pressure to a Maximum of 5000 PSI (350 BAR)			
	Pressure Media	Most Liquids and Gases - Please Consult Factory								
	Rated Electrical Excitation	10 VDC								
	Maximum Electrical Excitation	12 VDC								
	Input Impedance	1000 Ohms (Min.)								
OUTPUT	Output Impedance	1000 Ohms (Nom.)								
	Full Scale Output (FSO)	100 mV (Nom.)								
	Residual Unbalance	± 5 mV (Typ.)								
	Combined Non-Linearity, Hysteresis and Repeatability	± 0.1% FSO BFSL (Typ.) ± 0.5% FSO (Max.)								
	Resolution	Infinitesimal								
	Natural Frequency of Sensor Without Screen (KHz) (Typ.)	240	300	380	500	575	700	1000	1400	1650
	Acceleration Sensitivity % FS/g Perpendicular	5.0×10^{-4}	3.0×10^{-4}	1.5×10^{-4}	1.1×10^{-4}	9.0×10^{-5}	6.5×10^{-5}	4.0×10^{-5}	2.5×10^{-5}	1.9×10^{-5}
	Insulation Resistance	100 Megohm Min. @ 50 VDC								
ENVIRONMENTAL	Operating Temperature Range	-65°F to +750°F (-55°C to +400°C) - Pressure Sensing Area -65°F to +525°F (-55°C to +274°C) - Cable Area								
	Compensated Temperature Range	+80°F to +650°F (+25°C to +343°C)								
	Thermal Zero Shift	± 1.5% FS/100°F (Typ.)								
	Thermal Sensitivity Shift	± 1.5% /100°F (Typ.)								
	Linear Vibration	10-2,000 Hz Sine, 100g. (Max.)								
	Mechanical Shock	20g half Sine Wave 11 msec. Duration								
PHYSICAL	Electrical Connection	4 Conductor 30 AWG Shielded Cable (30" Before Module, 24" After Module)								
	Weight	8 Grams (Nom.) Excluding Cable								
	Pressure Sensing Principle	Fully Active Four Arm Wheatstone Bridge Dielectrically Isolated Silicon on Silicon Patented Leadless Technology								
	Mounting Torque	15 Inch-Pounds (Max.) 1.7 N-m								

Note: Requires external compensation module (Max. temp. 400°F) Please refer to outline drawing.
Note: Custom pressure ranges, accuracies and mechanical configurations available. Dimensions are in inches. Dimensions in parenthesis are in millimeters. All dimensions nominal. (K)
Continuous development and refinement of our products may result in specification changes without notice.
Kulite miniature pressure transducers are intended for use in test and research and development programs and are not necessarily designed to be used in production applications. For products designed to be used in production programs, please consult the factory.

KULITE SEMICONDUCTOR PRODUCTS, INC. • One Willow Tree Road • Leonia, New Jersey 07605 • Tel: 201 461-0900 • Fax: 201 461-0990 • http://www.kulite.com

Appendix B: References

1. Holmes, M. D., Parker, G. R., Dickson, P., Meyer, B. A. and Schmidt, C. C., "Pressure Dependence of Slow Cookoff Behavior in PBX 9502 Bucket Tests" *Proceedings of the 15th International Detonation Symposium*, pp. 1506-1517, San Francisco, CA, 2014.

2. Meyer, B. A., Schmidt, C. C. and Holmes, M. D., "Measurement of PBX 9502 Flow Parameters" *Los Alamos National Laboratory* 2014.

3. Holmes, M. D. and Parker, G. R., "Gas Generation of Heated PBX 9502" *Los Alamos National Laboratory Report: LA-UR-16-27752*, 2016.